NEW CLAIMS

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1.   Method for determining the yaw angle of a satellite,

    wherein a fixed cartesian coordinate system is defined
    with regard to the satellite, having a first axis which
10 is directed substantially tangential to the orbit of the
    satellite and defines a roll angle, having a second axis
    which is directed substantially perpendicular to the
    orbit plane of the satellite and defines a pitch angle,
    and having a third axis which is directed substantially
15 radial to the orbit of the satellite and defines a yaw
    angle,

    comprising the steps of:

20 providing a first angle sensor and a second angle sensor
    having different reference points and measuring the same
    angle about a measurement axis which is anti-parallel to
    the third axis,

25 evaluating a first angle and a second angle about the
    measurement axis on the basis of the angle sensors, and

    determining the yaw angle on the basis of the first
    angle and the second angle.

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2.   Method according to claim 1, wherein the measurement
    axis is the first axis.

3. Method according to claim 1, wherein the measurement axis is the second axis.

4. Method according to claim 3, wherein the satellite is a geo-stationary satellite, wherein the first angle sensor has its reference point at the center of earth (N) and the second angle sensor has its reference point at a ground station (G) located apart from the center of earth.

5. Method for determining the yaw angle of a satellite,

wherein a fixed cartesian coordinate system is defined with regard to the satellite, having a first axis which is directed substantially tangential to the orbit of the satellite and defines a roll angle, having a second axis which is directed substantially perpendicular to the orbit plane of the satellite and defines a pitch angle, and having a third axis which is directed substantially radial to the orbit of the satellite and defines a yaw angle,

comprising the steps of:

providing a first angle sensor and a set of angle sensors including a second and third angle sensor, wherein the first, second and third angle sensors measure angles about different measurement axes which are anti-parallel to the third axis and wherein for the first angle sensor and for the set of angle sensors different reference points are assigned,

evaluating measurement angles on the basis of the angle sensors, and

determining the yaw angle on the basis of the
measurement angles.

5   6.   Method according to claim 5, wherein the set of angle
sensors comprises a first roll angle sensor (R1) and a
first pitch angle sensor (P1) both related to a first
reference point (G), and wherein the first angle sensor
comprises a second roll angle sensor (R2) or a second

10   pitch angle sensor (P2), related to a second reference
point (N) which is different from the first reference
point (G).

   7.   Method according to claim 6, wherein for the first
15   sensor calculations are based on equations rep-
resentable by the following expression:

$$
\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(RM1) & -\sin(RM1) \\ 0 & \sin(RM1) & \cos(RM1) \end{bmatrix} \cdot \begin{bmatrix} \cos(PM1) & 0 & \sin(PM1) \\ 0 & 1 & 0 \\ -\sin(PM1) & 0 & \cos(PM1) \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} =
$$

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$$
\begin{bmatrix} \cos(Y) & -\sin(Y) & 0 \\ \sin(Y) & \cos(Y) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(R) & -\sin(R) \\ 0 & \sin(R) & \cos(R) \end{bmatrix} \cdot \begin{bmatrix} \cos(P) & 0 & \sin(P) \\ 0 & 1 & 0 \\ -\sin(P) & 0 & \cos(P) \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(RR1) & -\sin(RR1) \\ 0 & \sin(RR1) & \cos(RR1) \end{bmatrix} \cdot \begin{bmatrix} \cos(PR1) & 0 & \sin(PR1) \\ 0 & 1 & 0 \\ -\sin(PR1) & 0 & \cos(PR1) \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}
$$

25   and wherein for the second sensor calculations are based
on equations representable by the following expression:

$$
\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(RM2) & -\sin(RM2) \\ 0 & \sin(RM2) & \cos(RM2) \end{bmatrix} \cdot \begin{bmatrix} \cos(PM2) & 0 & \sin(PM2) \\ 0 & 1 & 0 \\ -\sin(PM2) & 0 & \cos(PM2) \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} =
$$

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$$
\begin{bmatrix} \cos(Y) & -\sin(Y) & 0 \\ \sin(Y) & \cos(Y) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(R) & -\sin(R) \\ 0 & \sin(R) & \cos(R) \end{bmatrix} \cdot \begin{bmatrix} \cos(P) & 0 & \sin(P) \\ 0 & 1 & 0 \\ -\sin(P) & 0 & \cos(P) \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(RR2) & -\sin(RR2) \\ 0 & \sin(RR2) & \cos(RR2) \end{bmatrix} \cdot \begin{bmatrix} \cos(PR2) & 0 & \sin(PR2) \\ 0 & 1 & 0 \\ -\sin(PR2) & 0 & \cos(PR2) \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}
$$

with

P, R, Y	pitch, roll yaw angle errors,
RRx, PRx	roll and pitch angles of the sensor's reference point, and
RMx, PMx	measured roll and pitch angles (from center of a star or from the center of earth),

wherein one of the measurements RMx or PMx could be unknown.

8. Method according to claim 7, wherein the first and the second reference points (G, N) are on the earth.

9. Method according to claim 8, wherein the first and/or second reference points (G, N) are on a star.

10. Method according to claim 9, wherein the satellite is a geo-stationary satellite.

11. Method according to claim 5, wherein the attitude of the satellite is determined by using the determined yaw angle.

12. Method for determining a calibrated value for a yaw angle of a satellite,

comprising the steps of:

storing a yaw angle profile over a quiet orbit,

determining a sample yaw angle at a calibration time (t0),

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determining a calibrated value by subtracting the sample
yaw angle with a yaw angle profile value having a time
shift in the yaw angle profile corresponding to the
5   calibration time (t0).

13.   Method for determining a calibrated value for a yaw
        angle of a satellite,

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10   storing for each angle sensor on board of the satellite
        a profile over a quiet orbit,

        determining a sample value for each of the angle sensors
        at a calibration time (t0),

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        determining calibrated values for each angle sensor by
        subtracting the sample values with a angle sensor
        profile value having a time shift in the respective
        angle sensor profile corresponding to the calibration
20   time (t0),

        determining a calibrated value for a yaw angle with
        calibrated values for each angle sensor.

25 14.   Apparatus for determining the yaw angle of a satellite,

        wherein a fixed cartesian coordinate system is defined
        with regard to the satellite, having a first axis which
        is directed substantially tangential to the orbit of the
30   satellite and defines a roll angle, having a second axis
        which is directed substantially perpendicular to the
        orbit plane of the satellite and defines a pitch angle,
        and having a third axis which is directed substantially

radial to the orbit of the satellite and defines a yaw angle,

comprising:

a first angle sensor and a second angle sensor having different reference points,

means for measuring the same angle about a measurement axis which is anti-parallel to the third axis,

means for evaluating a first angle and a second angle about the measurement axis on the basis of the angle sensors, and

means for determining the yaw angle on the basis of the first angle and the second angle.

15. Apparatus according to claim 14, wherein the measurement axis is the first axis.

16. Apparatus according to claim 14, wherein the measurement axis is the second axis.

17. Apparatus according to claim 16,
wherein the satellite is a geo-stationary satellite,
wherein the first angle sensor has its reference point at the center of earth (N) and the second angle sensor has its reference point at a ground station (G) located apart from the center of earth.

18. Apparatus for determining the yaw of a satellite,

wherein a fixed cartesian coordinate system is defined
with regard to the satellite, having a first axis which
is directed substantially tangential to the orbit of the
satellite and defines a roll angle, having a second axis

5   which is directed substantially perpendicular to the
orbit plane of the satellite and defines a pitch angle,
and having a third axis which is directed substantially
radial to the orbit of the satellite and defines a yaw
angle,

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comprising:

a first angle sensor and a set of angle sensors
including a second and third angle sensor,

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means for measuring by the first, second and third angle
sensors angles about different measurement axes which
are anti-parallel to the third axis, wherein for the
first angle sensor and for the set of angle sensors

20   different reference points are assigned,

means for evaluating measurement angles on the basis of
the angle sensors, and

25   means for determining the yaw angle on the basis of the
measurement angles.

19.   Apparatus according to claim 18, wherein the set of
angle sensors comprises a first roll angle sensor (R1)

30   and a first pitch angle sensor (P1) both related to a
first reference point (G), and wherein the first angle
sensor comprises a second roll angle sensor (R2) or a
second pitch angle sensor (P2), related to a second

reference point (N) which is different from the first
reference point (G).

20. Apparatus according to claim 19, wherein for the first
sensor calculations are based on equations representable
by the following expression:

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(RM1) & -\sin(RM1) \\ 0 & \sin(RM1) & \cos(RM1) \end{bmatrix} \cdot \begin{bmatrix} \cos(PM1) & 0 & \sin(PM1) \\ 0 & 1 & 0 \\ -\sin(PM1) & 0 & \cos(PM1) \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} =$$

$$\begin{bmatrix} \cos(Y) & -\sin(Y) & 0 \\ \sin(Y) & \cos(Y) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(R) & -\sin(R) \\ 0 & \sin(R) & \cos(R) \end{bmatrix} \cdot \begin{bmatrix} \cos(P) & 0 & \sin(P) \\ 0 & 1 & 0 \\ -\sin(P) & 0 & \cos(P) \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(RR1) & -\sin(RR1) \\ 0 & \sin(RR1) & \cos(RR1) \end{bmatrix} \cdot \begin{bmatrix} \cos(PR1) & 0 & \sin(PR1) \\ 0 & 1 & 0 \\ -\sin(PR1) & 0 & \cos(PR1) \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

and wherein for the second sensor calculations are based
on equations representable by the following expression:

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(RM2) & -\sin(RM2) \\ 0 & \sin(RM2) & \cos(RM2) \end{bmatrix} \cdot \begin{bmatrix} \cos(PM2) & 0 & \sin(PM2) \\ 0 & 1 & 0 \\ -\sin(PM2) & 0 & \cos(PM2) \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} =$$

$$\begin{bmatrix} \cos(Y) & -\sin(Y) & 0 \\ \sin(Y) & \cos(Y) & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(R) & -\sin(R) \\ 0 & \sin(R) & \cos(R) \end{bmatrix} \cdot \begin{bmatrix} \cos(P) & 0 & \sin(P) \\ 0 & 1 & 0 \\ -\sin(P) & 0 & \cos(P) \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(RR2) & -\sin(RR2) \\ 0 & \sin(RR2) & \cos(RR2) \end{bmatrix} \cdot \begin{bmatrix} \cos(PR2) & 0 & \sin(PR2) \\ 0 & 1 & 0 \\ -\sin(PR2) & 0 & \cos(PR2) \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

with

P, R, Y   pitch, roll yaw angle errors,

RRx, PRx   roll and pitch angles of the sensor's
reference point, and

RMx, PMx   measured roll and pitch angles (from
center of a star or from the center of
earth),

wherein one of the measurements RMx or PMx could be
unknown.

21. Apparatus according to claim 20, wherein the first and the second reference points (G, N) are on the earth.

22. Apparatus according to claim 21, wherein the first and/or second reference points (G, N) are on a star.

23. Apparatus according to claim 21, wherein the satellite is a geo-stationary satellite.

24. Apparatus according to claim 23, wherein comprising means for determining the attitude of a satellite.

25. Apparatus for determining a calibrated value for a yaw angle of a satellite,

    comprising:

    means for storing a yaw angle profile over a quiet orbit,

    means for determining a sample yaw angle at a calibration time (t0),

    means for determining a calibrated value by subtracting the sample yaw angle with a yaw angle profile value having a time shift in the yaw angle profile corresponding to the calibration time (t0).

26. Apparatus for determining a calibrated value for a yaw angle of a satellite,

means for storing for each angle sensor on board of the
satellite a profile over a quiet orbit,

5   means for determining a sample value for each of the
angle sensors at a calibration time (t0),

means for determining calibrated values for each angle
sensor by subtracting the sample values with a angle
10   sensor profile value having a time shift in the
respective angle sensor profile corresponding to the
calibration time (t0),

means for determining a calibrated value for a yaw angle
15   with calibrated values for each angle sensor.